EARTHQUAKE PROBABILITIES FOR THE WASATCH FRONT REGION IN UTAH, IDAHO, AND WYOMING

by Working Group on Utah Earthquake Probabilities

EXECUTIVE SUMMARY

In a letter to *The Salt Lake Daily Tribune* in September 1883, U.S. Geological Survey (USGS) geologist G.K. Gilbert warned local residents about the implications of observable fault scarps along the western base of the Wasatch Range. The scarps were evidence that large surface-rupturing earthquakes had occurred in the past and more would likely occur in the future. The main actor in this drama is the 350-km-long Wasatch fault zone (WFZ), which extends from central Utah to southernmost Idaho. The modern Wasatch Front urban corridor, which follows the valleys on the WFZ's hanging wall between Brigham City and Nephi, is home to nearly 80% of Utah's population of 3 million. Adding to this circumstance of "lots of eggs in one basket," more than 75% of Utah's economy is concentrated along the Wasatch Front in Utah's four largest counties, literally astride the five central and most active segments of the WFZ.

Since the late 1960s, abundant paleoseismic data on the timing and size of prehistoric surface-rupturing earthquakes have been collected on the WFZ and other faults in Utah's Wasatch Front region, which extends into southeastern Idaho and southwestern Wyoming (Figure ES-1). Motivated, in part, by the recent development of improved methods to analyze paleoseismic data, a Working Group on Utah Earthquake Probabilities (WGUEP) was formed in January 2010, under the auspices of the Utah Geological Survey (UGS) and the USGS, to evaluate the probabilities of future occurrence of moderate-to-large earthquakes in the Wasatch Front region. The working group consisted of 14 geologists, seismologists, and engineers affiliated with diverse Federal, State, academic, and consulting organizations.

The WGUEP's goal was to develop probabilistic earthquake forecasts for the Wasatch Front region that include: (1) combined time-dependent and time-independent probabilities of large earthquakes for the five central segments of the WFZ and two segments of the Great Salt Lake fault zone, (2) time-independent probabilities for less well-studied faults, and (3) estimates of the time-independent probabilities of background earthquakes not associated with known or mapped faults in the moment magnitude (**M**) 5.0 to 6.75 range.

The WGUEP provides these forecasts with the hope that they will help heighten the public's awareness and understanding of the region's seismic hazards, just as the forecasts of the Working Groups on California Earthquake Probabilities (WGCEP) have successfully done. Our consensus-based time-dependent and time-independent earthquake probabilities in the Wasatch Front region are not only useful for regional hazard analyses, they also provide a robust basis for site-specific probabilistic seismic hazard analyses (PSHAs) for the safe design and evaluation of critical structures and facilities. Further, our time-dependent probabilities for fault ruptures can be incorporated into the PSHAs that will underpin urban seismic hazard maps planned by the USGS for the Wasatch Front region. Additionally, our earthquake forecasts can aid in developing public policies leading to more effective, sustained earthquake mitigation efforts in the Wasatch Front region.

Similar to the approach used by the 2008 WGCEP, the WGUEP methodology relies on four basic model components: a seismic source model, a deformation model, an earthquake rate model, and a probability model. In general, the seismic source model characterizes the physical geometry of the known faults; the deformation model gives recurrence intervals and/or slip rates for each fault segment and/or fault; the earthquake rate model gives the long-term rate of all earthquakes throughout the region above a specified threshold (in this case **M** 5.0 and greater); and the probability model gives a probability for earthquakes of different size over a specified time period. However, some significant differences exist between the WGUEP and the 2008 WGCEP model components; the WGUEP counterparts are much simpler due in large part to the availability of robust paleoseismic data for the WFZ and other faults in the Wasatch Front region.

Our probability model describes how earthquakes are distributed in time. The simplest version is the time-*independent* Poisson (memoryless) model, which assumes that each earthquake is completely independent of the timing of all other events. For example, with this model it makes no difference in the forecast for the Salt Lake City segment whether its last rupture occurred yesterday or 1,000 years ago. Following the lead of the 2008 WGCEP, we have used only one time-*dependent* model, the Brownian Passage Time (BPT) model. The BPT model is a stress-renewal model that computes the probability of each segment rupturing conditioned on the length of time since the last event.

The WGUEP seismic source model consists of six groups of seismic sources: (1) the five central segments of the WFZ, (2) the end segments of the WFZ, (3) the combined Oquirrh–Great Salt Lake fault zone (OGSLFZ), (4) antithetic fault pairs (two faults that intersect each other at depth and may rupture coseismically), (5) significant other faults

in the Wasatch Front region, and (6) crustal background earthquakes. Background earthquakes are defined as those events less than **M** 6.75 ± 0.25 that cannot be associated with a known fault. A classic example of a background earthquake within the Wasatch Front region is the 1975 **M** 6.0 Pocatello Valley, Idaho, earthquake.

The 350-km-long WFZ consists of 10 segments that are thought to have ruptured repeatedly and independently in large magnitude (**M** ≥ 6.75) earthquakes. The five central segments from north to south are the Brigham City, Weber, Salt Lake City, Provo, and Nephi segments (Figure ES-1). These central segments are thought to be the most hazardous, because each segment has had multiple large Holocene (past 11,700 yrs) earthquakes that have produced surface rupture. Detailed geologic investigations at 23 paleoseismic sites on these segments have yielded data on the timing of past earthquakes and/or measured single-event fault displacements. The resulting data show that at least four to five earthquakes large enough to cause surface rupture have occurred on each central segment in the past ~6000 years. Despite the abundant paleoseismic data, a number of important questions needed to be considered in the WGUEP forecast. For example, although the paleoseismic data generally support the prevailing segmentation model for the WFZ, is it possible that adjacent segments have ruptured together, in whole or part, during a single large earthquake? To address the questions and reduce uncertainties in the sizes and timing of past events, we extensively and systematically reviewed and analyzed all of the available paleoseismic data for the five central segments.

At least 22 surface-faulting earthquakes have ruptured the central segments of the WFZ since about 6000 years ago, based on our analysis of all of the paleoseismic data and assuming that each earthquake ruptured a single segment of the fault zone. Using our revised surface-faulting earthquake histories for each segment, we calculated inter-event and mean recurrence intervals, which indicate a moderately periodic pattern of earthquake recurrence on the central WFZ as a whole: inter-event times for the segments range from 700 to 2700 years, and mean recurrence intervals range from 900 to 1500 years, similar to a composite mean recurrence interval for the central WFZ of about 1200 years.

Although we favor single-segment ruptures as the dominant earthquake process on the WFZ, we addressed uncertainties in the model by constructing rupture models that include both single- and multi-segment ruptures and by defining spatial uncertainties in the segment-boundary locations. We developed the models following our evaluation of possible multi-segment ruptures, which relied mostly on per-segment earthquake timing and displacement data. A companion *unsegmented* model allows potential "floating" ruptures along the WFZ that ignore the location of segment boundaries, thus complementing the range of possible ruptures included in the segmented models. The single-segment rupture model received more weight than those including multi-segment ruptures based on the significant timing differences in the youngest and best-constrained earthquakes along the fault, unique surface-faulting histories per segment, displacement-per-event data, and the presence of prominent bends or stepovers in the fault trace and/or basin depth changes at the segment boundaries. Characteristic magnitudes for the central WFZ segments range from a best-estimate **M** 7.1 for the Brigham City segment to **M** 7.3 for the Provo segment.

In addition to examining the central WFZ segments, we reviewed and evaluated paleoseismic data for other faults in the region to develop rupture models, characteristic earthquake, and rate information (earthquake timing and/or fault slip rates) for input into the WGUEP forecasts. These other faults included: (1) the end segments of the WFZ; (2) the OGSLFZ, particularly the Antelope Island and Fremont Island segments of the Great Salt Lake fault; (3) antithetic fault pairs such as the West Valley fault zone and the Salt Lake City segment of the WFZ; and (4) 45 other faults in the Wasatch Front region.

Paleoseismic data for the five central segments of the WFZ as well as the Antelope Island and Fremont Island segments of the Great Salt Lake fault zone are sufficiently robust that we analyzed them in both a time-dependent and time-independent manner. The WFZ end segments, the Oquirrh fault zone, and all other faults were treated solely in the traditional time-independent manner due to insufficient information for a time-dependent analysis.

The background earthquake model depicts the fraction of future mainshocks in the Wasatch Front region that are expected to occur on seismic sources other than faults identified in the WGUEP fault model. For purposes of the WGUEP forecast, the background earthquake model provides rates for future mainshocks of **M** 5.0 or greater up to a maximum of **M** 6.75 ± 0.25. The probabilities for background earthquakes were treated only in a time-independent manner.

We compiled and processed an up-to-date historical and instrumental earthquake catalog for the background earthquake model that meets the needs of state-of-practice seismic hazard analysis, namely a catalog that: (1) is complete in terms of accounting for all known earthquakes in the magnitude range of interest; (2) assigns a uniform moment magnitude to each event; (3) identifies "dependent" events (foreshocks, aftershocks, and the smaller events of earthquake swarms) in earthquake clusters that can be removed for statistical analysis of mainshock recurrence parameters; (4) excludes non-tectonic seismic events such as blasts and mining-induced seismicity; and (5) quantifies the uncertainty and rounding error associated with the assigned magnitude of each earthquake.

Geodetic data were used in the most recent WGCEP forecasts and are increasingly being used in probabilistic seismic hazard analyses to estimate fault slip rates. Because of

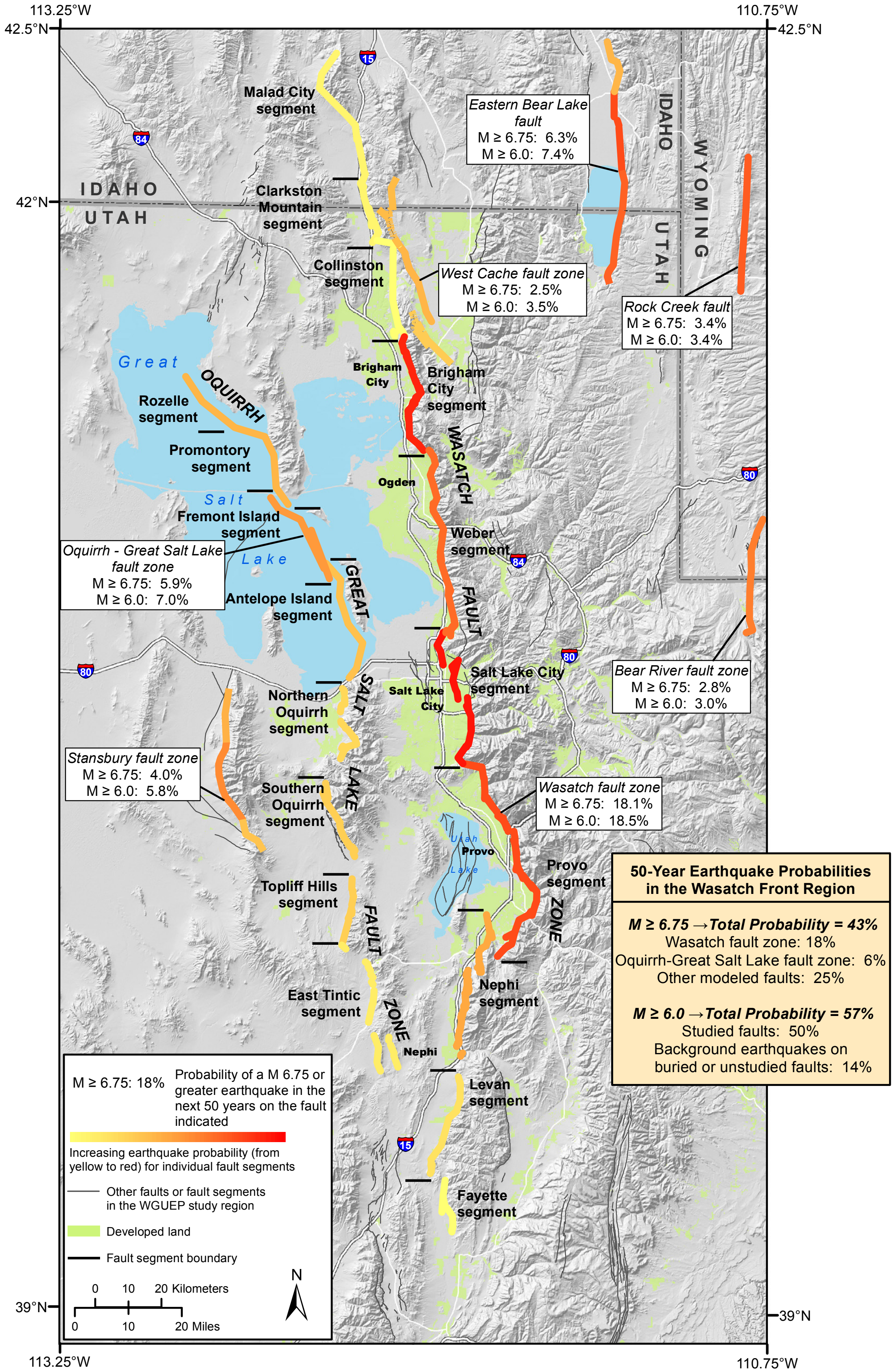

Figure ES-1. Probabilities of one or more earthquakes of **M** 6.0 and 6.75 or greater in the next 50 years (2014–2063) in the Wasatch Front region. “Other modeled faults” are those faults other than the Wasatch and the Oquirrh–Great Salt Lake fault zones. “Studied faults” include the Wasatch and Oquirrh–Great Salt Lake fault zones and the other modeled faults. Shaded topography generated from 90-m digital elevation data (https://eros.usgs.gov/elevation-products).

discrepancies observed in previous studies between geodetic moment rates and geological/seismological moment rates in the Wasatch Front region, we compared these rates for both the Wasatch Front region as a whole and four subregions. The geodetic moment rates for the Wasatch Front region, and for three of its four subregions, are consistent with the geological/seismological moment rates calculated for the WGUEP earthquake rate model. The geodetic moment rates are not consistent with the WGUEP earthquake rate model in the fourth subregion, an area that encompasses the Levan and Fayette segments of the WFZ. Further work is needed to identify the cause of this moment rate discrepancy; however, regardless of the cause of the discrepancy, we do not expect it to significantly affect the WGUEP forecast for the Wasatch Front region as a whole.

Based on the inputs summarized above, Figures ES-1 and ES-2 summarize earthquake probabilities in the Wasatch Front region in the next 50 years. The probability of one or more large (**M** ≥ 6.75) earthquakes occurring in the Wasatch Front region in the time period of 2014 to 2063 is 43%. This regional probability is for earthquakes on all of the characterized faults and the background seismicity. The probability of one or more earthquakes of **M** 6.0 or larger in the Wasatch Front region in the next 50 years is 57% (Figure ES-1). In addition to the probabilities shown on Figures ES-1 ans ES-2, the probability of one or more earthquakes of **M** 5.0 or larger in the Wasatch Front region in the next 50 years is 93%.

A significant contribution to these total probabilities comes from the WFZ and OGSLFZ. The total probability of at least one earthquake of **M** 6.75 or larger on either of these two fault zones is 23% in the next 50 years. The total probability from the other modeled faults is 25% due in part to some significant contributions from faults with higher slip rates such as the Eastern Bear Lake and Stansbury fault zones (Figure ES-1). The Eastern Bear Lake fault has a probability of 6.3% for one or more earthquakes of **M** 6.75 or larger in the next 50 years (Figure ES-1). For one or more earthquakes of **M** 6.0 or larger on the other faults, the 50-year probability is 34%. For background earthquakes of **M** 6.0 or larger on buried or unknown faults, the 50-year probability is 14%.

Figure ES-2 shows the 50-year probabilities for earthquakes of **M** 6.75 or larger on selected fault segments. For example, the probabilities on the Salt Lake City, Brigham City, Provo, and Weber segments are 5.8%, 5.6%, 3.9%, and 3.2%, respectively. The 50-year probability on the Nephi segment is relatively low at only 1.8% because its most recent rupture occurred only about 300 years ago. Although these individual probabilities might seem small, the total probability for an earthquake of **M** 6.75 or larger somewhere on the WFZ in the next 50 years is 18%. In the next 100 years, the probability increases to 33%. Such a large earthquake occurring anywhere along the WFZ will result in significant damage to communities in the Wasatch Front region and to the economy of the region as a whole (e.g., see Earthquake Engineering Research Institute, 2015).

Considering that the average age of Utah's citizens is the youngest in the nation with a median age of 29.2 years, there is a realistic chance that many current residents of the Wasatch Front region will experience a large earthquake in their lifetimes. Preparing for earthquakes requires an awareness that even earthquakes in the **M** 5 range can cause significant localized damage in urbanized areas, and the probability of earthquakes of this size occurring in the coming decades is very high.

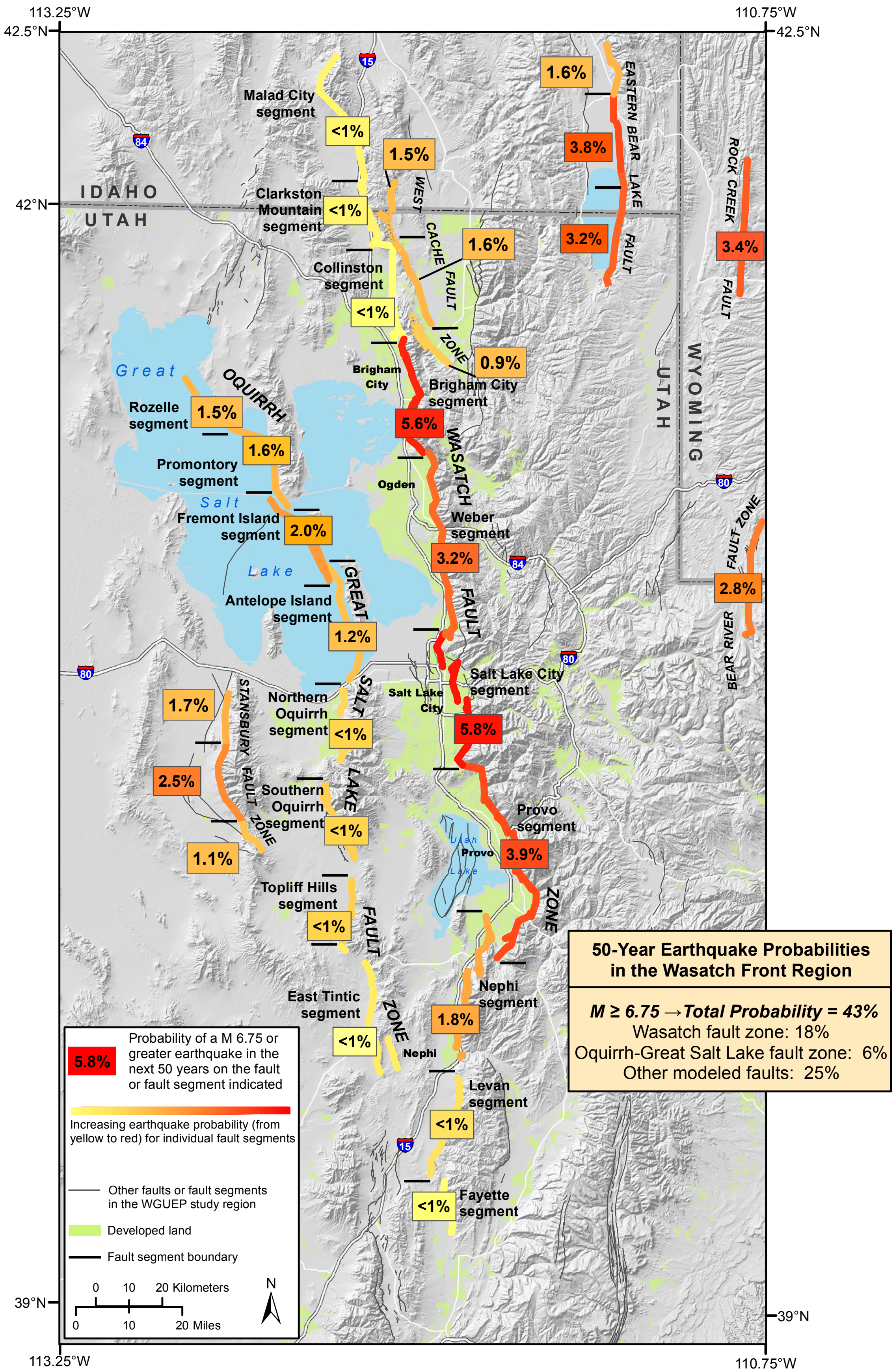

Figure ES-2. Probability of one or more earthquakes of **M** 6.75 and greater in the next 50 years on selected fault segments. Shaded topography generated from 90-m digital elevation data (https://eros.usgs.gov/elevation-products).